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"THE RIGHT STUFF", FARMING BY LOCATION

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Abstract

A satellite-based positioning system is being developed to determine the location of farm equipment while working in the field. A satellite receiver mounted in a moving tractor or combine calculates position coordinates based on signals received from a selection of satellites in the Department of Defense Global Positioning System (GPS). The position coordinates are retrieved from the receiver by a computer and combined in a common data base with additional information collected by the computer such as yield, soil fertility, soil moisture, temperature, implement draft, and fuel consumption. There are a number of possible applications for this system. One is the automation of position information and data collection for research purposes. Comparison of results between years can be easily made. Another application is the optimized and automated application of manure, fertilizers and chemicals. Profits can be increased and environmental damage minimized.

Introduction

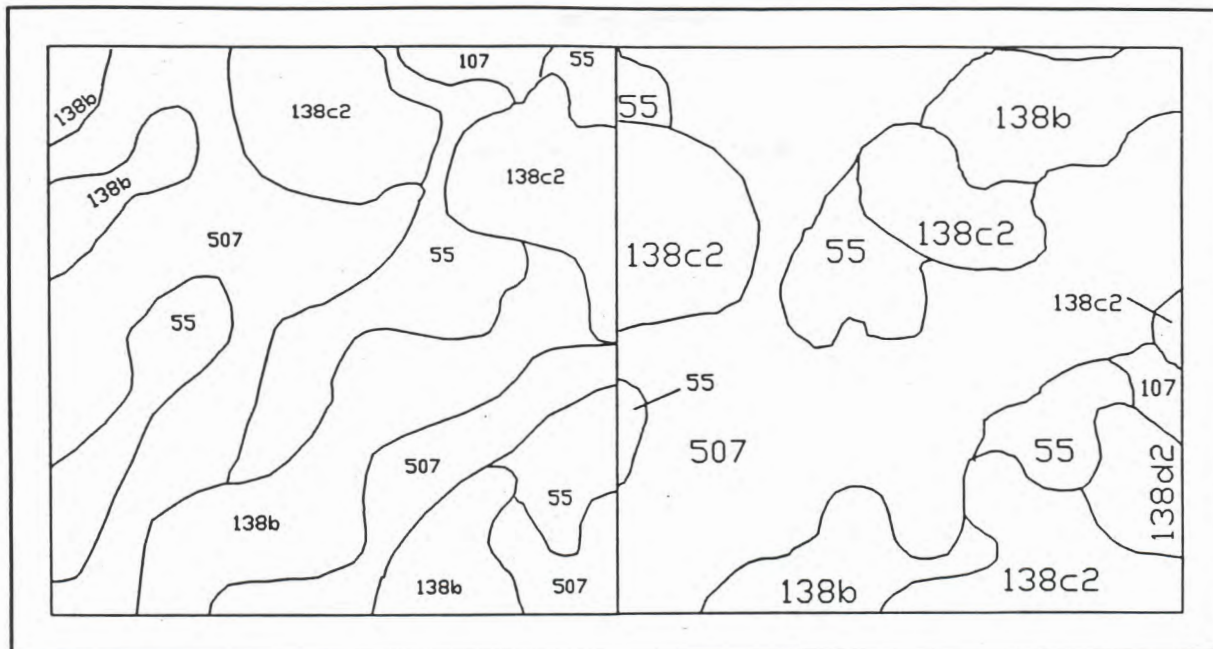
This paper describes the development of a satellite positioning system used to determine location of farm equipment while working in a field. The paper is organized into four sections. In the first section, the purpose and applications of the system are described. This is followed by a review of current techniques of position determination and recent research into positioning. The next section describes the operation of the system being developed at the National Soil Tilth Laboratory and Iowa State University. The final section discusses the current status of the system and future development.

Purpose of Positioning System

Position information for farm equipment is useful for a wide variety of applications both in production and research. On commercial farms, operators are searching for ways to reduce monetary costs and environmental damage by minimizing the amounts of fertilizers, herbicides, and pesticides applied. A number of systems have been or are being developed that combine soil characteristics, yields, fertility, weed pressure and pest problems in a common data base with all data referenced to position in the field. These data are then used to minimize the amount of chemicals applied to the crops and soil, consistent with economic production. Obviously, accurate and timely position information is essential to proper operation of these systems.

Position information systems are also important in University and on-farm research. Research trials typically run from 3 to 10 years or longer. Accurate and repeatable positioning information is a requirement for the meaningful comparison of results from year to year. An example of on-farm research being conducted by the National Soil Tilth Laboratory is shown in Figure 1. That figure shows the map of soil types on two 16.2 hectare (40 acre) tracts. The two tracts are on adjacent farms in Boone County, Iowa. The management of one farm follows conventional tillage, crop rotation and chemical treatment practices. The management of the other farm uses alternative tillage practices, applies herbicides and pesticides selectively and at low rates and substitutes manure, sewage sludge and legumes for commercial fertilizers. The purpose of the Tilth Laboratory research is to compare the effects of the two management systems on the agroecosystem of each area. The project is multidisciplinary. Comparison of the effects of the two management systems on rainfall infiltration, water gradients, soil physical characteristics, soil chemistry and nutrient levels, soil biology (focusing on earthworm populations), crop yields and microclimates are being made. All of these investigations are tied to soil type and location.

An example of data being collected is shown in Table 1. Corn yields as a function of soil type are shown for 1989. These yields were determined by harvesting small plots along transects of the research tracts. The yields for all plots were grouped by soil type and averaged to determine the mean yields. The position of the harvester was determined manually (dead reckoning) and the yield measurement was performed as a batch as opposed to a continuous process. Thus the entire 12.2 x 2.1 meter (40 x 7 foot) plot was harvested and then the weight and moisture measured with the combine stopped. This manual process of determining position and yield has two major problems: it is subject to error and it is inefficient. Automated position and yield monitoring can eliminate both problems. Use of GPS to determine position in real time and a computer to continuously monitor the yield and integrate that information with the position information into a common database is one of the goals of this project. The database will then be used as an input into a Geographic Information System (GIS).



Map Unit	Soil Type	Classification
6	Okoboji silty clay loam 0 to 1% slope	(Cumulic Haplaquoll)
55	Nicollet loam, 1 to 3% slope	(Aquic Hapludoll)
107	Webster silty clay loam 0 to 2% slope	(Typic Haplaquoll)
138B	Clarion loam, 2 to 5% slope	(Typic Haplaquoll)
138C	Clarion loam, 5 to 9% slope	
138C2	Clarion loam, 5 to 9% slope, moderately eroded	
138D2	Clarion loam, 9 to 14% slope, moderately eroded	
507	Canisteo silty clay loam 0 to 2% slope	(Typic Haplaquoll)

FIGURE 1. Research site 32.37 hectares (80 acres) for comparing conventional (left) and alternate (right) farming systems in Boone County, Iowa.

Soil Map Unit	Conventional Yield		Alternative Yield	
	<u>M³/HA</u>	<u>BU/AC</u>	<u>M³/HA</u>	<u>BU/AC</u>
55	13.3	152.5	13.1	150.4
138B	13.0	148.7	12.2	139.8
507	13.3	153.0	12.2	139.8
107	12.2	140.4	13.3	152.7
138C2	11.3	129.5	11.8	135.2
138D2	----	----	9.9	114.1

TABLE 1. Conventional vs. Alternative Farm System Corn Yields for 1989.

Techniques of Position Determination - Current and Emerging

There are five main categories of position sensing that have been used for farm vehicles: mechanical systems, leader-cable, ultrasonic, ranging, and navigational.

Mechanical sensing systems include those that employ contact sensors mounted on the tractor to detect crop rows, or sensors that follow furrows. Neither of these techniques are suitable for automatic position sensing for the purpose of data collection or selective control of the application of fertilizers and pesticides.

In leader cable systems, wire is buried under the ground and energized with audio frequency current. The magnetic field is detected by search coils mounted on the farm vehicle. The system is not suitable because it does not permit easy changing of field row patterns, and is extremely expensive to install.

Ultrasonic systems are similar to mechanical contact sensing with the contact feelers being replaced with ultrasonic emitters which detect presence of crop rows, or furrows by sensing reflected sound energy. Like mechanical sensing, this technique is not suitable for the applications under consideration.

Ranging systems are based on surveying techniques where some form of electromagnetic energy (RF, infrared, light) is generated on the moving vehicle. This energy returns to the moving vehicle after striking two or more reflectors at known locations. The tractor position is then determined by triangulation. Palmer (1989) has employed this technique successfully using RF energy with fixed transmitters and a mobile receiver. The disadvantages of this system are limited range, and the need to maintain the reflectors or transmitters under adverse environmental conditions. Gordon and Holmes (1988) used laser energy and achieved six meter accuracy, but only over a range of 300 meters. Heil et al. (1986) developed a microwave positioning system for agricultural vehicles and reported good results at distances of up to 578 meters.

Interest in navigational systems, particularly those tied to the Global Positioning System, has increased in recent years. Larsen et al. (1988) discussed a system similar to the one described in this paper.

Position Information System - Description of Operation

The position information system being developed at the National Soil Tilth Laboratory and Iowa State University uses a satellite receiver to collect signals from the Department of Defense Global Positioning System (GPS) satellites. The receiver, which is mounted on the farm equipment, uses these signals to calculate the position of the equipment in the field. That position information is then collected by a computer and maybe combined with other

information of interest in a common database for future analysis. Or it may be combined with position-dependent information collected at some earlier time and used to perform real time control of equipment operations. As described previously, this real-time control can include optimizing application of manure, fertilizer and chemicals, so that excess application of material is avoided and environmental damage is prevented. Both the data collection and real time control functions are done automatically, without the intervention of the operator. A detailed description of operation will now be given.

Operation of the Global Positioning System

The Global Positioning System consists of a number of satellites in fixed, known orbits around the earth. Each satellite transmits two carrier frequencies: the L1 carrier at 1,575.42 MHz and the L2 carrier at 1,227.6 MHz. The carriers are modulated with two types of code and a navigation message. The two codes used to modulate the carriers are the P code (precision code) and the C/A code (course/acquisition code). Either code can be used to determine position, with the P code providing 10 to 20 meter accuracy and the C/A code providing 20 to 30 meter accuracy (Georgiadou and Doucet, 1990). Only the C/A code is available for unrestricted civilian use.

A receiver based on earth that acquires signals broadcast by 3 or more satellites can use the signals to compute its latitude and longitude.

The receivers may be operated in one of two modes: stand alone or differential. In the stand alone mode, the receiver operates exactly as described above, receiving signals from satellites and calculating position using those signals. The receiver calculates the position in the following manner. As mentioned previously, the satellites modulate the L1 and L2 carriers with the P code, C/A code and navigation information. The navigation information includes the orbital position of the satellite. Therefore, by demodulating the carriers, the receiver can obtain the position of the satellite. The receiver can also measure the time required for each satellite signal acquired to travel from the satellite to the receiver. The receiver accomplishes this by generating a code identical to the satellite code (P code for military receivers and C/A code for commercial receivers). The receiver then code locks this replica with the received code by shifting the start time of the replica until maximum correlation is obtained. Since the receiver knows the nominal starting time, T_s , for the received code (which is repeated at regular predetermined intervals) and it knows the time shift, T_r , required to obtain code lock, it knows the time for the signal to travel from satellite to the receiver, which is just the difference between the nominal start time for the satellite signal and the start time for the receiver replica. Multiplying this transit time by the speed of light gives the nominal distance (or pseudo range) between the satellite and the receiver:

$$P = (T_r - T_s)c$$

This distance can also be expressed as the vector distance between satellite and receiver using earth-based coordinates:

$$P=\sqrt{[(U_s-U_r)^2+(V_s-V_r)^2+(W_s-W_r)^2]}$$

This equation contains three unknowns, the position coordinates of the receiver = (U_r , V_r , W_r). If signals from three satellites are acquired, then these unknowns can be determined:

$$P1=\sqrt{(U_{s1}-U_r)^2+(V_{s1}-V_r)^2+(W_{s1}-W_r)^2}$$

$$P2=\sqrt{(U_{s2}-U_r)^2+(V_{s2}-V_r)^2+(W_{s2}-W_r)^2}$$

$$P3=\sqrt{(U_{s3}-U_r)^2+(V_{s3}-V_r)^2+(W_{s3}-W_r)^2}$$

If signals from four satellites are acquired, then a term can be added to correct for the receiver clock error giving the following equations (Leick, 1990, pp. 205-206):

$$P1=\sqrt{(U_{s1}-U_r)^2+(V_{s1}-V_r)^2+(W_{s1}-W_r)^2}+dTr*c$$

$$P2=\sqrt{(U_{s2}-U_r)^2+(V_{s2}-V_r)^2+(W_{s2}-W_r)^2}+dTr*c$$

$$P3=\sqrt{(U_{s3}-U_r)^2+(V_{s3}-V_r)^2+(W_{s3}-W_r)^2}+dTr*c$$

$$P4=\sqrt{(U_{s4}-U_r)^2+(V_{s4}-V_r)^2+(W_{s4}-W_r)^2}+dTr*c$$

There are a number of errors associated with the stand-alone mode of operation. These include errors in the satellite atomic clocks, geometric resolution errors, and errors associated with propagation through the atmosphere. All of these errors can be eliminated by operating the system in the differential mode. In differential mode the receiver, in addition to monitoring satellite signals, will receive error information from a remote base station located at some known position. The base station will also be monitoring satellite signals. In addition the base station will have preprogrammed into its memory its precise location. The base station will compare that position with the position computed using the satellite signals. The difference between known and calculated locations will then be transmitted to the receiver mounted on the equipment. The receiver will adjust its calculated position using that difference. This entire process is accomplished in real time.

Operation of the Farm Equipment Position Information System.

The farm equipment position information system being developed at the National Soil Tilth Laboratory is shown in Figure 2. The system as shown consists of a GPS mobile receiver, radios, RF modems, a GPS base station receiver, a datalogger, and a computer. The purpose of this

particular system is to collect equipment performance information as a function of equipment position.

The data collection is accomplished as follows. A variety of sensors monitoring tractor performance are connected to the datalogger. These sensors include fuel input and return sensors, a radar ground speed sensor, an axle speed sensor, and an equipment drawbar draft sensor. The datalogger monitors the sensors and stores their current values in memory.

At the same time that data is being collected, the equipment position and velocity are being determined by the GPS satellite receiver mounted on the farm equipment. The receiver is operated in the differential mode and is therefore linked via radio to a base station positioned at some known location. The base station also receives signals from the GPS satellites and calculates position based on those signals. The position is then compared with the known position of the base station and the difference (or error) is calculated. The error is then sent to the mobile station which uses the error to determine its actual position more precisely.

The position and equipment performance information is collected by an IBM compatible, environmentally hardened personal computer. For the system currently under development, the program running on the PC collects the position information from the receiver and the performance information from the datalogger and combines the two sets of data in a single file. The data are time stamped so that the file contains performance information as a function of position and time. Position and performance information are collected every one second. For a tractor running at 8 km/hr (5 mph) that corresponds to a resolution of about 2.3 meters (7.5 feet).

The combined information is then transformed into a format compatible with the GIS database software. The database is then used to create archival records, make year by year comparisons, and make comparisons with other position-based information collected at the same location.

Position Information System - Current Status

At the time this article was completed (6/15/91), the status of the National Soil Tilth Laboratory satellite based positioning system was as follows. The stand-alone system became operational in early May and was put to use on the ISU research farms collecting information for an ongoing tillage and herbicide experiment. The differential system operation was verified in the lab and a preliminary calibration run made around the ISU campus to estimate the position accuracy in the differential mode. The preliminary test indicated a worst case error of 12 meters. Integration with the GIS database was also begun.

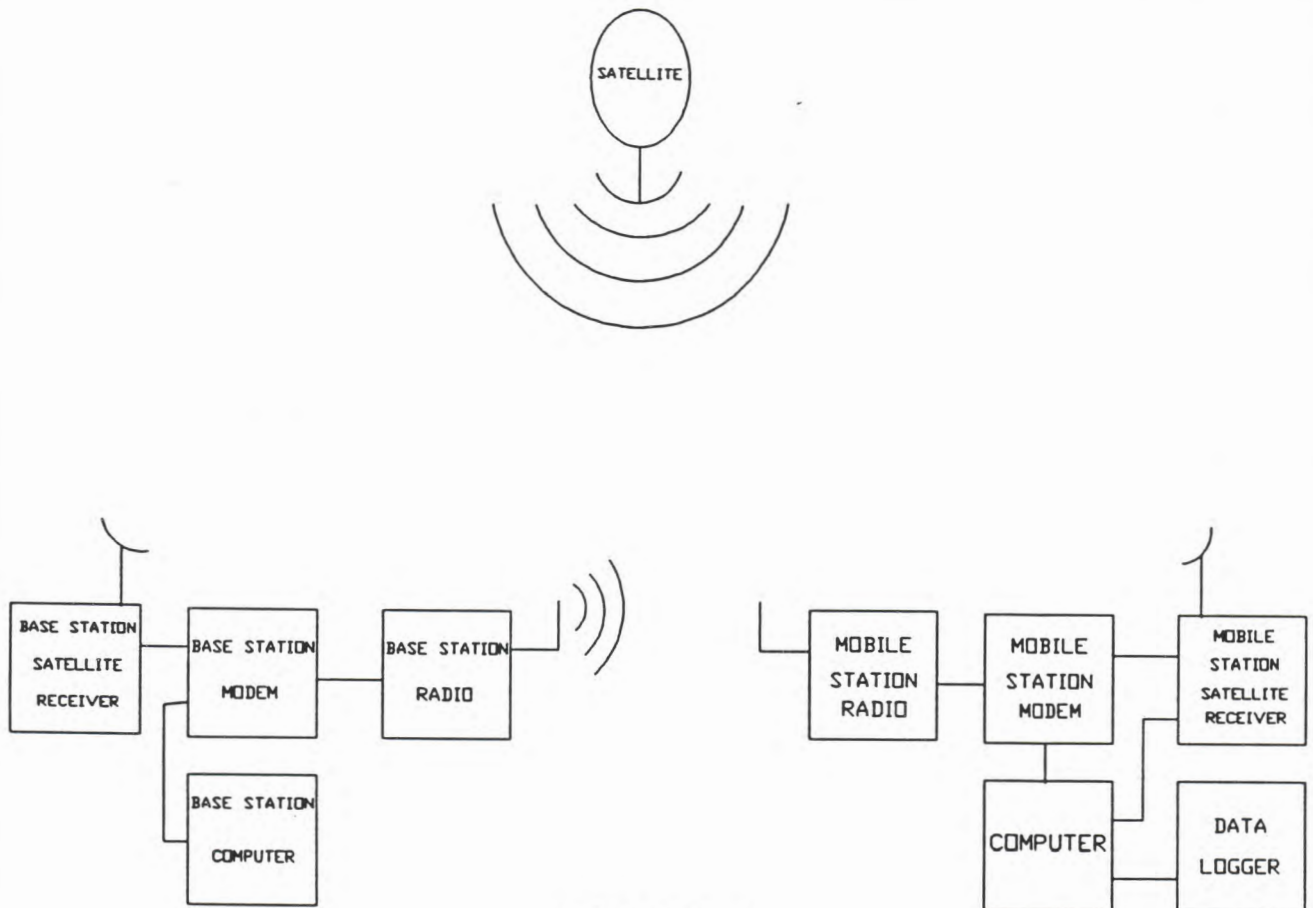


FIGURE 2
SATELLITE BASED POSITIONING SYSTEM

Summary

The position sensing system for farm equipment is being developed using the Global Positioning System. When operational, the system will permit automatic combination of vehicle position information with research data (yield, vehicle performance, soil properties). Data and position will be combined in a common database and used for analysis. The database can also be used to control future farm operations to optimize the amount of fertilizers and chemicals applied, thereby maximizing profits and protecting the environment.

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